Timing Properties of CVD-Diamond Detectors at RelativisticVelocities*

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Heavy-Ion Induced Transient Currents (TC)

In order to investigate the behaviour of Single-Crystal CVD-Diamond Detectors (SC-DD) at relativistic ion velocities, we measured original TC Signals (TCS) induced by ^{132}Xe ions of 215AMeV in a SC-DD of a thickness d_D =400µm and a capacitance C_D=0.9pF. At a rate of 1.6kHz, a charge Q_G^{Xe} =1.2*10^8 e-h pairs/ion was generated in the diamond bulk. We present a data discussion according to the theory of Space-Charge Limited Current transients (SCLC) [1], expected for $Q_G > Q_{BI,}$ with $Q_{BI} = C_D * V_D$ the bias-induced charge at the electrodes of the sensor.

The ^{132}Xe pulses were recorded with a 1GHz DSO of 10GS/s resolution, connected to the diamond via a high-frequency transmission line of 30m lengths. We compare the shapes of the ^{132}Xe transients with α-signals measured in the laboratory using a broadband amplifier and a 3GHz DSO. Each α-particle generates a charge of $Q_G^{\alpha} = 4.2*10^5$ e-h pairs within the α-range of 12µm, and represents the 'small-signal case' at 'single-carrier drift'.

Figure 1 shows average ^{132}Xe transients obtained in the bias range 10V≤ $|V_D|$ ≤ 800V (solid and dotted lines) and an average α-signal (dashed line) measured at V_D=800V. Note, the α-amplitude is magnified by an arbitrary factor.

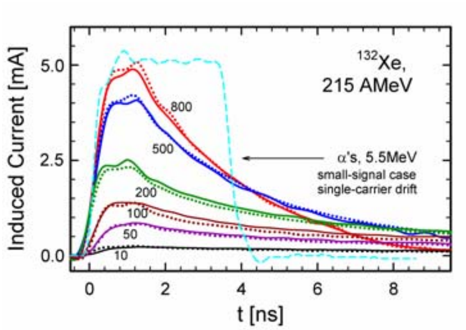

Figure 1: Original TCS obtained in the bias range 10V ≤ $|V_D|$ ≤ 800V from ^{132}Xe ions of 215AMeV (solid and dotted lines). A ^{241}Am-α-transient (dashed line) represents the 'small-signal case' at 'single-carrier drift'. (see text)

The RC_D time constant of the circuit was as short as 45ps at 50Ω impedance. In addition, the bias resistor of 10kΩ ensured a constant voltage on the electrodes at all times, and the measurements were performed in the so-called 'current mode'. The flat top of the α-signal demonstrates the homogeneity of the internal drift field and the absence of trapping and recombination. The right 'kink' indicates the arrival of the leading hole to the backward, grounded electrode and the top width defines the transition time t_{Tr}. In contrary to the prompt signal decay in the 'small-signal case', ^{132}Xe-generated TCS show much longer relaxation time (≈7ns), given by the time needed to expel all space charge from the crystal. Charge expulsion is supported by free carriers present in the neutral detector at thermal equilibrium. Hence, it is faster for low-quality diamond detectors, e.g. for polycrystalline sensors.

The rising slope dI/dt of the ^{132}Xe TCS was maintained at t_{rt} ≤ 200ps. The area of pulses recorded at $|V_D|$ ≥ 25V were equal to the theoretically predicted charge of Q_G = 19.22pC, indicating a charge-collection efficiency near to unit. The transition time t_{Tr} decreased from t_{Tr}=3ns for the 'small-signal' case to t_{SCLC} = 650ps for the ^{132}Xe transients. This effect was expected, however not only because of the 'dual-carrier drift'. According to the standard SCLC theory, the transit time drops also at 'single-carrier drift' to a constant value $t_{SCLC} = 0.78*t_{Tr}$ in the transition from the 'small-signal' case to the SCLC case. In our experiment, t_{Tr} saturates for $|V_D|$ ≥ 50V, and that is evident to the onset of SCLC for Q_G^{Xe} ≥ 45pC (i.e., two ions in a time in the counter). The almost same level of both 'kinks', confirms equal mobility of electrons and holes and the absence of bulk trapping.

Time Resolution for Relativistic Protons

We tested the time resolution of SC-DD using 3.5GeV protons and a new low-capacitance broadband amplifier designed for the diamond start detectors of the HADES spectrometer. Two SC-DD of a thickness d=300µm, equipped with 3mm circular electrodes segmented in four quadrants, were mounted each on an amplifier pcb in order to minimize stray capacitances. Figure 2 shows the time spectrum obtained with two opposite diamond segments aligned in the proton beam. The intrinsic resolution σ ≈ 107ps achieved, is a significant milestone towards the difficult goal of a σ_{MIP}< 100ps. The tail is due to boarder events of longer drift time - an unavoidable experimental drawback in measurements where relativistic particles are used to test sensors smaller than the beam spots.

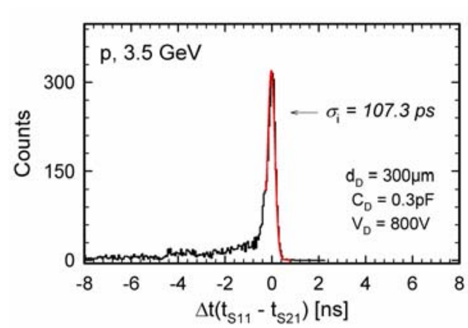

Figure 2: Time resolution of SC-DD for 3.5GeV protons measured with a low-capacitance broadband amplifier.

References

[1] G. Juška *et al.*, Phil. Mag. B 69 (1994) 277

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